IN THE SPECIFICATION

Please amend page 1 by inserting the following heading between the title of the invention and the first paragraph:

"FIELD OF THE INVENTION"

Please amend page 1 by inserting the following heading between the first and second paragraphs:

"BACKGROUND OF THE INVENTION"

Please amend page 2 by inserting the following heading on line 17:

"SUMMARY OF THE INVENTION"

Please amend page 9 by inserting the following heading on line 4:

"BRIEF DESCRIPTION OF THE DRAWINGS"

Please amend page 9 by inserting the following heading on line 30:

"DETAILED DESCRIPTION OF THE INVENTION"

Please amend page 16 by inserting the following language between the "CLAIMS" heading and claim 1:

"I/We claim:"

Please amend pages 2-8 by deleting the text beginning on page 2 line 24 and ending on page 8 line 14 as follows:

"~~Actively controlling the axial position of the rotors within the stator in real time in response, for example, to operational conditions within the pump allows a clearance between the rotors and the stator to be increased, decreased or maintained at a constant level as necessary during use of the pump. For example, the rotor to stator clearance can be increased or even maximised when the pump is switched off following pumping of sticky or~~

~~dusty atmospheres, so as to prevent problems occurring upon restart. The axial clearance between rotor and stator can fill with process deposits during operation, and when the pump is stopped the rotors will cool and shrink on to the process deposits, potentially locking the pump. Moving the rotors relative to the stator can allow the axial clearance to increase when the pump is stopped, thereby increasing the likelihood of the pump restarting. Once the pump has started, the axial clearance can then be reduced back to a normal running clearance during operation of the pump.~~

~~Alternatively, or additionally, the rotors can be actively moved closer to the stator surface during use of the pump to scrape off process media built up on the stator surface.~~

~~The rotor to stator clearance may also be controlled to optimise pump performance for different pumped gas species. For example, the clearance can be decreased or increased when pumping hydrogen or an inert gas such as argon so as to achieve optimum performance without pump seizure.~~

~~This movement of the rotors within the stator can significantly reduce the effect of operational variables, such as backpressure, running temperatures and gas type, on pump performance. Furthermore, the ability to actively control rotor position can relax the manufacturing precision of components. This can bring a significant reduction in cost due to the potential removal of grinding operations and the reduction in scrap levels.~~

~~For example, in one embodiment the pump comprises means for effecting axial movement of the rotors in response to an axial load generated in the rotors during operation of the pump. When in operation, internal pressure within a pump produces an axial thrust load in the rotor. This thrust load is proportional to the amount of gas compression work being performed by the pump and hence the input power requirements of the pump. For example, the efficiency of gas compression of a screw pump is, to a large extent, dictated by the clearance between the internal surface of the stator which carries the screw threaded rotors and the rotors themselves. Where the rotors are tapered, they may be moved both simultaneously and synchronously away from the stator face effectively increasing the radial clearance, reducing the compression and hence the power input requirements. Similarly, tapered Roots rotors may be moved both simultaneously and synchronously away from the stator face effectively~~

~~increasing the radial clearance, reducing the compression and hence the power input requirements.~~

~~Each rotor is typically mounted on, or integral with, a respective shaft rotatably mounted within the pump, the pump comprising a bearing assembly for rotatably supporting the shafts relative to the stator. In preferred embodiments, the means for effecting axial movement of the rotors comprises means for moving the bearing assembly relative to the stator. For example, in one embodiment, the bearing assembly is free to move in an axial direction within a housing, the means for effecting axial movement of the rotors comprising a spring mechanism arranged with respect to a rotor such that when the rotor is subjected to an axial load, the spring mechanism compresses or extends causing an axial reactive load.~~

~~When an axial load generated in a rotor tends to cause axial displacement of the rotor and bearing assembly, the spring may be compressed or extended (depending on its position). Assuming the load does not exceed the elastic limit of the spring, the spring will react to vary the axial position of the rotor. By selecting a spring with a suitable spring constant, the arrangement can be used to vary the rotor to stator clearance giving a relatively constant level of gas compression work over a wide range of inlet pressures, thereby moderating the power input requirements of the pump.~~

~~In other embodiments, the pump comprises control means for actively controlling operation of the means for effecting axial movement of the rotors. For example, a piston or other actuator may be provided for moving the rotors, the control means controlling movement of the actuator to control the axial position of the rotors. In preferred embodiments, the control means controls a motor adapted to rotate a drive shaft that engages the actuator so as to axially move the actuator relative to the stator with rotation of the drive shaft. The drive shaft may, for example, comprise a lead screw passing through a conformingly threaded aperture in the actuator. Alternatively, the control means may comprise one or more electromagnets for moving the actuator.~~

~~Any other convenient mechanism for accurately moving the rotors relative to the stator may be provided. For example, a piezoelectric actuator may be provided, which deforms in response to a voltage supplied thereto by the control means to move the rotors within the~~

~~stator. Alternatively, a metallic ring, tube or other element can be provided, which is selectively heated by the control means so that the resulting thermal expansion of the element causes the rotors to move within the stator. The most appropriate mechanism can be chosen for the extent of the required movement of the rotors relative to the stator. For example, for Northey rotors, the maximum required movement may be less than 100 microns, whereas for tapered screw rotors the required movement may be around 1 mm.~~

~~Where movement of the rotors is effected by movement of the bearing assembly relative to the stator, the actuator may conveniently comprise part of, or is carried by, a housing for the bearing assembly. The housing for the bearing assembly preferably carries an internal sealing mechanism for the pump. This bearing assembly preferably supports one end of each shaft, with a second bearing assembly being provided for supporting the other end of each shaft. This bearing assembly may be fixed relative to the stator or may be arranged to move with the shafts. A housing for this latter second bearing assembly may also carry an internal sealing mechanism for the pump. This can ensure that movement of the shafts relative to the stator does not compromise the internal pump sealing.~~

~~One or both of the housings for the bearing assemblies may define an end surface of the stator so that the end surface moves with the rotors as the axial position of the rotors is adjusted, thereby avoiding collision between the ends of the rotors and the end surfaces of the stator by maintaining a constant clearance between the ends of the rotors and the end surfaces of the stator.~~

~~The control device may be configured to receive a signal indicative of an operational parameter of the pump, and to control the axial position of the rotors in dependence of this signal. The operational parameter may include one of the temperature of and/or within the stator, ultimate vacuum calibration at start up, backpressure, exhaust temperature, power consumption and inlet pressure. In relation to temperature, cooling water upsets could create a problem in that thermal shocking can distort the stator to such an extent that the rotor makes contact with the stator. By measuring the stator temperature and incoming water temperature, it is possible to detect the onset of a seizure condition and protect the pump by increasing the rotor to stator clearance as thermal shock occurs. High backpressure results in an increase in internal gas temperature and rotor to stator differential, which could lead to~~

~~pump seizure. By measuring the internal gas temperature it is possible to modify the rotor to stator clearance to accommodate the increase in backpressure. In relation to power consumption, the control device may be configured to receive a signal indicative of the power consumption of a motor for rotating the rotors, and to control actuation of the actuator in response thereto.~~

~~Alternatively, or in addition, the control means may comprise a sensor for detecting the size, or the rate of change, of the clearance between the rotors and the stator, and is configured to control the means for effecting axial movement of the rotors in response to an output from the sensor. The sensor may be conveniently provided by a Hall effect sensor. The sensor can be calibrated by determining the position of the rotors within the pump when there is zero axial clearance between the rotors and the stator. This could be achieved by moving the rotors axially until contact occurs (with the rotors non-rotational) either before use or once the pump has warmed up in order to account for thermal effects. Alternatively, these thermal effects could be built into the control means, so that they are taken into account when determining the size of the axial clearance from a signal output from the sensor.~~

~~The means for effecting axial movement of the rotors is preferably arranged so as to ensure both rotors are maintained in the same axial position, but may also be configured so as to permit relative axial movement between the rotors. Typically, such relative movement will be within the limits of rotor contact and might be used with the rotors in operation to scrape off process media build up on the flanks of the rotors or to allow fine tuning of the timing. The relative movement between the rotors can be achieved using independent means for effecting axial movement of each rotor, for example respective actuator arrangements as previously mentioned. An associated control device may be configured to actuate movement of the rotors independently of one another. This could be done while the rotors are stationary by monitoring the achievable travel of a rotor, or while operating at full speed by monitoring shaft torque or motor current.~~

~~Where the rotors have intermeshing screw threads, at least part of the screw threads preferably has an outside diameter that tapers decreasingly in a direction from the pump inlet to the exhaust of the pump. In one embodiment, each screw thread has a diameter that gradually decreases from the pump inlet to the exhaust. In another embodiment, only part of~~

~~the screw thread of each rotor has an outside diameter that tapers towards the exhaust of the pump, the remainder of the screw thread having a substantially constant diameter. There are a number of advantages particularly associated with this latter embodiment. Firstly, vacuum pump exhaust gas temperatures vary with running conditions, and have an effect on the rotor to stator clearance at the exhaust (low vacuum) end of the pump. Control of the rotor to stator clearance in the exhaust stages allows the optimisation of performance and power consumption. The inlet (high vacuum) temperature does not vary as considerably as the exhaust and hence rotor to stator control in the inlet stages is of lesser importance. Secondly, during roughing (pumping large volumes of gas at or near atmospheric pressure) performance can be optimised by bypassing the low vacuum stages of the pump. The rotor to stator clearance in the exhaust stages can be increased to act as a pressure relief valve, with the rotor to stator clearance at the inlet stages remaining constant so as to maximise pumping efficiency. Where the rotors are, at least in part, tapered, the size of the radial clearance between the rotors and the stator can be determined from the size of the axial clearance between the rotors and the stator. The relationship between the axial and the radial clearances can be established during testing.~~

~~The rotors may be pulsed between two axial positions to remove process deposits in the axial clearances between the rotors and the stator. For example, the control device may be configured to move the rotors at a first speed in one axial direction to increase the axial clearance between the rotors and the stator, and to move the rotors at a second speed different from the first speed to decrease the axial clearance between the rotors and the stator. In order to prevent tripping of the pump motor, the rate of decrease of the axial clearance is preferably greater than the rate of increase of the axial clearance. A linear encoder may be provided to prevent seizure at the extremities of the axial positions of the rotors.~~"

Please amend page 9 by deleting the text on line 1 and ending on line 2 as follows:

"~~Features described above in relation to the first aspect of the invention are equally applicable to the method aspects of the invention, and vice versa.~~"

Please amend page 9 by inserting the following text before line 31 as follows:

"In accordance with one aspect of the present invention, there is provided a dry pump comprising a stator housing first and second intermeshing rotors adapted for counter-rotation within the stator, and means for effecting axial movement of the rotors within the stator to vary at least one clearance between the rotors and the stator during use of the pump.

Actively controlling the axial position of the rotors within the stator in real time in response, for example, to operational conditions within the pump allows a clearance between the rotors and the stator to be increased, decreased or maintained at a constant level as necessary during use of the pump. For example, the rotor to stator clearance can be increased or even maximised when the pump is switched off following pumping of sticky or dusty atmospheres, so as to prevent problems occurring upon restart. The axial clearance between rotor and stator can fill with process deposits during operation, and when the pump is stopped the rotors will cool and shrink on to the process deposits, potentially locking the pump. Moving the rotors relative to the stator can allow the axial clearance to increase when the pump is stopped, thereby increasing the likelihood of the pump restarting. Once the pump has started, the axial clearance can then be reduced back to a normal running clearance during operation of the pump.

Alternatively, or additionally, the rotors can be actively moved closer to the stator surface during use of the pump to scrape off process media built up on the stator surface.

The rotor to stator clearance may also be controlled to optimise pump performance for different pumped gas species. For example, the clearance can be decreased or increased when pumping hydrogen or an inert gas such as argon so as to achieve optimum performance without pump seizure.

This movement of the rotors within the stator can significantly reduce the effect of operational variables, such as backpressure, running temperatures and gas type, on pump performance. Furthermore, the ability to actively control rotor position can relax the manufacturing precision of components. This can bring a significant reduction in cost due to the potential removal of grinding operations and the reduction in scrap levels.

For example, in one embodiment the pump comprises means for effecting axial movement of the rotors in response to an axial load generated in the rotors during operation of the pump. When in operation, internal pressure within a pump produces an axial thrust load in the rotor. This thrust load is proportional to the amount of gas compression work being performed by the pump and hence the input power requirements of the pump. For example, the efficiency of gas compression of a screw pump is, to a large extent, dictated by the clearance between the internal surface of the stator which carries the screw threaded rotors and the rotors themselves. Where the rotors are tapered, they may be moved both simultaneously and synchronously away from the stator face effectively increasing the radial clearance, reducing the compression and hence the power input requirements. Similarly, tapered Roots rotors may be moved both simultaneously and synchronously away from the stator face effectively increasing the radial clearance, reducing the compression and hence the power input requirements.

Each rotor is typically mounted on, or integral with, a respective shaft rotatably mounted within the pump, the pump comprising a bearing assembly for rotatably supporting the shafts relative to the stator. In preferred embodiments, the means for effecting axial movement of the rotors comprises means for moving the bearing assembly relative to the stator. For example, in one embodiment, the bearing assembly is free to move in an axial direction within a housing, the means for effecting axial movement of the rotors comprising a spring mechanism arranged with respect to a rotor such that when the rotor is subjected to an axial load, the spring mechanism compresses or extends causing an axial reactive load.

When an axial load generated in a rotor tends to cause axial displacement of the rotor and bearing assembly, the spring may be compressed or extended (depending on its position). Assuming the load does not exceed the elastic limit of the spring, the spring will react to vary the axial position of the rotor. By selecting a spring with a suitable spring constant, the arrangement can be used to vary the rotor to stator clearance giving a relatively constant level of gas compression work over a wide range of inlet pressures, thereby moderating the power input requirements of the pump.

In other embodiments, the pump comprises control means for actively controlling operation of the means for effecting axial movement of the rotors. For example, a piston or other

actuator may be provided for moving the rotors, the control means controlling movement of the actuator to control the axial position of the rotors. In preferred embodiments, the control means controls a motor adapted to rotate a drive shaft that engages the actuator so as to axially move the actuator relative to the stator with rotation of the drive shaft. The drive shaft may, for example, comprise a lead screw passing through a conformingly-threaded aperture in the actuator. Alternatively, the control means may comprise one or more electromagnets for moving the actuator.

Any other convenient mechanism for accurately moving the rotors relative to the stator may be provided. For example, a piezoelectric actuator may be provided, which deforms in response to a voltage supplied thereto by the control means to move the rotors within the stator. Alternatively, a metallic ring, tube or other element can be provided, which is selectively heated by the control means so that the resulting thermal expansion of the element causes the rotors to move within the stator. The most appropriate mechanism can be chosen for the extent of the required movement of the rotors relative to the stator. For example, for Northey rotors, the maximum required movement may be less than 100 microns, whereas for tapered screw rotors the required movement may be around 1 mm.

Where movement of the rotors is effected by movement of the bearing assembly relative to the stator, the actuator may conveniently comprise part of, or is carried by, a housing for the bearing assembly. The housing for the bearing assembly preferably carries an internal sealing mechanism for the pump. This bearing assembly preferably supports one end of each shaft, with a second bearing assembly being provided for supporting the other end of each shaft. This bearing assembly may be fixed relative to the stator or may be arranged to move with the shafts. A housing for this latter second bearing assembly may also carry an internal sealing mechanism for the pump. This can ensure that movement of the shafts relative to the stator does not compromise the internal pump sealing.

One or both of the housings for the bearing assemblies may define an end surface of the stator so that the end surface moves with the rotors as the axial position of the rotors is adjusted, thereby avoiding collision between the ends of the rotors and the end surfaces of the stator by maintaining a constant clearance between the ends of the rotors and the end surfaces of the stator.

The control device may be configured to receive a signal indicative of an operational parameter of the pump, and to control the axial position of the rotors in dependence of this signal. The operational parameter may include one of the temperature of and/or within the stator, ultimate vacuum calibration at start up, backpressure, exhaust temperature, power consumption and inlet pressure. In relation to temperature, cooling water upsets could create a problem in that thermal shocking can distort the stator to such an extent that the rotor makes contact with the stator. By measuring the stator temperature and incoming water temperature, it is possible to detect the onset of a seizure condition and protect the pump by increasing the rotor to stator clearance as thermal shock occurs. High backpressure results in an increase in internal gas temperature and rotor to stator differential, which could lead to pump seizure. By measuring the internal gas temperature it is possible to modify the rotor to stator clearance to accommodate the increase in backpressure. In relation to power consumption, the control device may be configured to receive a signal indicative of the power consumption of a motor for rotating the rotors, and to control actuation of the actuator in response thereto.

Alternatively, or in addition, the control means may comprise a sensor for detecting the size, or the rate of change, of the clearance between the rotors and the stator, and is configured to control the means for effecting axial movement of the rotors in response to an output from the sensor. The sensor may be conveniently provided by a Hall effect sensor. The sensor can be calibrated by determining the position of the rotors within the pump when there is zero axial clearance between the rotors and the stator. This could be achieved by moving the rotors axially until contact occurs (with the rotors non-rotational) either before use or once the pump has warmed up in order to account for thermal effects. Alternatively, these thermal effects could be built into the control means, so that they are taken into account when determining the size of the axial clearance from a signal output from the sensor.

The means for effecting axial movement of the rotors is preferably arranged so as to ensure both rotors are maintained in the same axial position, but may also be configured so as to permit relative axial movement between the rotors. Typically, such relative movement will be within the limits of rotor contact and might be used with the rotors in operation to scrape off process media build up on the flanks of the rotors or to allow fine tuning of the timing.

The relative movement between the rotors can be achieved using independent means for effecting axial movement of each rotor, for example respective actuator arrangements as previously mentioned. An associated control device may be configured to actuate movement of the rotors independently of one another. This could be done while the rotors are stationary by monitoring the achievable travel of a rotor, or while operating at full speed by monitoring shaft torque or motor current.

Where the rotors have intermeshing screw threads, at least part of the screw threads preferably has an outside diameter that tapers decreasingly in a direction from the pump inlet to the exhaust of the pump. In one embodiment, each screw thread has a diameter that gradually decreases from the pump inlet to the exhaust. In another embodiment, only part of the screw thread of each rotor has an outside diameter that tapers towards the exhaust of the pump, the remainder of the screw thread having a substantially constant diameter. There are a number of advantages particularly associated with this latter embodiment. Firstly, vacuum pump exhaust gas temperatures vary with running conditions, and have an effect on the rotor to stator clearance at the exhaust (low vacuum) end of the pump. Control of the rotor to stator clearance in the exhaust stages allows the optimisation of performance and power consumption. The inlet (high vacuum) temperature does not vary as considerably as the exhaust and hence rotor to stator control in the inlet stages is of lesser importance. Secondly, during roughing (pumping large volumes of gas at or near atmospheric pressure) performance can be optimised by bypassing the low vacuum stages of the pump. The rotor to stator clearance in the exhaust stages can be increased to act as a pressure relief valve, with the rotor to stator clearance at the inlet stages remaining constant so as to maximise pumping efficiency. Where the rotors are, at least in part, tapered, the size of the radial clearance between the rotors and the stator can be determined from the size of the axial clearance between the rotors and the stator. The relationship between the axial and the radial clearances can be established during testing.

The rotors may be pulsed between two axial positions to remove process deposits in the axial clearances between the rotors and the stator. For example, the control device may be configured to move the rotors at a first speed in one axial direction to increase the axial clearance between the rotors and the stator, and to move the rotors at a second speed different from the first speed to decrease the axial clearance between the rotors and the stator. In

order to prevent tripping of the pump motor, the rate of decrease of the axial clearance is preferably greater than the rate of increase of the axial clearance. A linear encoder may be provided to prevent seizure at the extremities of the axial positions of the rotors.

In a second aspect, the present invention provides a method of controlling operation of a pump comprising a stator housing first and second intermeshing rotors adapted for counter-rotation within the stator, the method comprising the steps of axially moving the rotors relative to the stator to increase an axial clearance between the rotors and the stator when rotors are stationary, subsequently starting rotor rotation, and, during rotor rotation, axially moving the rotors relative to the stator to decrease the axial clearance between the rotors and the stator.

The method may further comprise subsequently, and preferably repeatedly, increasing and decreasing the axial clearance during use of the pump to remove deposits from the axial clearance. Thus, in a third aspect the present invention provides a method of controlling operation of a pump comprising a stator housing first and second intermeshing rotors adapted for counter-rotation within the stator, the method comprising the steps of sequentially axially moving the rotors in opposite directions relative to the stator to periodically vary an axial clearance between the rotors and the stator to remove deposits from the axial clearance.

Features described above in relation to the first aspect of the invention are equally applicable to the method aspects of the invention, and vice versa."